WL-TR-96-3068

SMOKE DETECTOR OPERABILITY AND RELIABILITY IN MILITARY FAMILY HOUSING

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AIR BASE TECHNOLOGY BRANCH

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An evaluation of the operability and reliability of smoke detectors currently installed in military family housing was conducted. The evaluation was conducted at four different bases and included a sufficient number of housing units to establish a high confidence level in the predicted operability and reliability rates. The four bases surveyed were Tyndall AFB, FL; Columbus AFB, MS; Maxwell/Gunter AFB, AL; and Keesler AFB, MS. A total of 369 detectors manufactured by 12 different companies were tested. One hundred and eighty nine were photoelectric, and 180 were ionization detectors. Three hundred and sixty (96.7%) were operative. Except for Tyndall AFB, all of the detectors tested were installed in the 1970s. One hundred and five (55.6%) of the photoelectric detectors were found to be less sensitive than specified by the manufacturer. None were found to be more sensitive than specified.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this test program was to determine the operability/reliability of the installed smoke detectors in Military Family Housing (MFH) units, and to determine if the smoke detectors lose their sensitivity or become more sensitive and prone to false alarms with age. This test program was requested by HQ AFCESA/DFE and funded by HQ USAF/CEH. It will determine what changes are necessary in smoke detectors to make them more reliable.

B. BACKGROUND

Recent technical studies by the Consumer Products Safety Commission (CPSC) have raised concerns about the operability and reliability of smoke detectors. The majority of Military Family Housing smoke detectors were installed in the mid 1970's and early 1980 time frame. The study accomplished by the CPSC indicated that the internal configuration of an individual device has a great deal to do with determining the service life of the device. Devices with push connectors and pressure contacts are much more likely to fail over time than devices with soldered connections. Failure of detectors to activate during actual fire incidents within residences raised Air Force concerns for the safety provided by smoke detectors including determining the usable life of these devices. Bases reported that smoke detectors failed to operate when exposed to smoke even though they appeared to work when following the manufacturer's test procedures.

C. SCOPE

An evaluation of the operability and reliability of smoke detectors currently installed in military family housing was conducted. The evaluation was conducted at four different bases and included a sufficient number of housing units to establish a high confidence level in the predicted operability and reliability rates. The four bases surveyed were Tyndall AFB, FL; Columbus AFB, MS; Maxwell/Gunter AFB, AL; and Keesler AFB, MS.

Field testing was performed on site using a Model 501 Aerosol Generator/Smoke Detector Analyzer, manufactured by Gemini Scientific Corp. Testing was conducted in accordance with the Test Protocol recommended by Gemini Scientific Corp. This Test Protocol (extracted from the Model 501 User's Manual) is summarized in Section II.

Laboratory analysis was conducted on all units failing to meet the UL Standard during field testing. A sampling of fully operable units was made to determine the degradation of these units with respect to time. Primary interest was the build up of residue, corrosion of contact points, loss of sensitivity due to degradation of light sending and receiving sources and changes in current associated with the degradation of radiation sources or contamination in the ionization chamber.

D. CONCLUSIONS

1. The results of the study shows that the Air Force has a serious problem in providing reliable smoke detection against life threatening hazards in residential dwellings.

2. The problems of **non detection** were found to be exclusive to optical smoke detectors. Ionization detectors though they are a nuisance when they become dirty, or malfunction; alarm therefore the occupant knows the detector is in need of replacement. Optical detectors on the other hand become dirty with time, causing insensitivity to smoke. This condition goes unrecognized by the occupant because it appears to be trouble free. However, the detector may no longer alarm to smoke. The Air Force study shows that 55.6% of the optical detectors tested would not function as required to meet the UL standard. Whereas, the ionization detectors achieved a 98.5% operability rating.

3. Photoelectric detector units can be cleaned! However, the detectors are often damaged during this process, and each manufacturer offers a different cleaning technique for each detector, making the process not only difficult but unreliable. The skill required to clean the detector is far in excess of housing occupants capability. If cleaning is accomplished by maintenance personnel who do not perform the task often, they often break the detector or cause damage which leaves little confidence in the future performance of the unit.

4. Ionization detector units are highly reliable in detecting low levels of smoke or cooking vapors. This capability makes them **extremely effective** in early warning of fire, however, if often makes them a **severe nuisance** when located too close the cooking source. Care should be used to locate ionization detectors a sufficient distance from the cooking area as to not cause the occupants to disconnect the units due to nuisance problems. The advantage of ionization detectors over photoelectric detectors is that the ionization detector will alarm when it becomes dirty and non functional, whereas the photoelectric detector will provide no indication to the occupant that it will not alarm to smoke. Some manufacturers provide a sensitivity detection capability for photoelectric units, however this reflection device often becomes dirty and does not provide the level of safety as originally designed.

5. Battery backup for detector units caused serious problems. "Chirping" of the detector unit indicates to the occupant that the battery is "dead or missing". These units were found disconnected though fully capable of operating in the AC powered mode. This "nuisance" situation occurs, due to the **short lifetime of the battery** since manufacturers do not provide the detectors with a recharging capability. Occupants typically disconnect the unit when the battery fails.

E. RECOMMENDATIONS

1. Use **only** AC powered detector units (exclude battery powered or battery backup units).

2. Use **only** ionization detectors in areas where there is a potential of cooking vapors causing the unit to be fouled.

3. Use **only** photoelectric detectors that have a reflecting test capability, these detectors should be limited to areas with the least possibility of fouling.

4. Replace photoelectric detectors at a **maximum of ten years** life when located in bed rooms, and other low fouling areas. Ionization detectors will nuisance alarm when they need replacing.

5. Replace ionization detectors located adjacent to cooking areas (high fouling areas) at a **maximum of five years** life to prevent occupant removal due to nuisance alarms.

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PREFACE

This report was prepared by the Wright Laboratory, Air Base Technology Branch, Infrastructure Technology Section (WL/FIVCF), Tyndall AFB, FL 32403.

The smoke detector test program was requested by HQ AFCESA/DFE and funded by HQ USAF/CEH. Tests were conducted at Tyndall AFB on 2-3 Dec 94, at Maxwell/Gunter AFB on 3-6 Jan 95, at Columbus AFB on 12-16 Dec 94, and at Keesler AFB on 23-27 Jan 95. A total of 369 residential smoke detection units were tested.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this test program was to determine the operability/reliability of the installed smoke detectors in Military Family Housing units and to determine if the smoke detectors lose their sensitivity or become more sensitive and prone to false alarms with age. This test was requested by HQ AFCESA/DFE and funded by HQ USAF/CEH.

B. BACKGROUND

Recently Grissom AFB experienced a kitchen fire where a smoke detector failed to operate even though the house was filled with considerable smoke. The base then tested all their detectors with canned smoke and found approximately five percent of their detectors would not give an alarm in the presence of smoke, even though they did sound an alarm when the test button was pushed. It has been shown that many detectors will respond to aerosol smoke; however they will not respond to levels of smoke from an actual fire within the manufactured sensitivity range.

Nationally, residential smoke detectors pose a significant problem resulting in an estimated 3,600 fire related deaths each year and nearly 22,000 fire injures[1].

A recent study by the Consumer Products Safety Commission (CPSC), plus the experience at Grissom AFB, has raised concern about the operability and reliability of the smoke detectors protecting USAF family housing residents. The vast majority of smoke detectors in Air Force family housing were installed in the 1976 to 1980 time frame. While a few of the detector manufacturers have established a service life for smoke detectors, none of the listing/approval agencies have established a mandatory replacement time frame.

Two major types of smoke detectors are available. The Air Force has a mix of both ionization and photoelectric detectors which are used interchangeably. Ionization devices contain a small radioactive source for ionizing the air molecules between a pair of electrodes, providing a very small current flow between the electrodes. If smoke particles from a fire enter this space, they reduce the flow of current by adhering to the ionization molecules. The drop in current sets off a buzzer or other alarm. The second type of smoke detector uses a photoelectric cell. In these detectors, smoke deflects a light ray from a diode causing it to enter a light sensitive cell. Photoelectric detectors are typically less sensitive than ionization detectors due to the more physical rather than electrical nature of their detection method.

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[1] Charles L. Smith, *Smoke Detector Operability Survey - Report on Findings,* Bethesda, Md.: U.S. Consumer Product Safety Commission, November 1993, Appendix B, p. 18.

Nationally, about 71 percent of smoke detectors are battery powered, and about 26 percent are operated by Alternating Current (AC) power. This data has significance because the major reason found in the CPSC survey for detectors being non-operational was missing or bad batteries. Seventy-six percent of the surveyed detectors contained radioactive material labels, indicating that they were ionization detectors; 11 percent did not, indicating that they probably were photoelectric detectors.[2] Nuisance alarms are more prevalent with ionization detectors than with photoelectric detectors. Early detectors (prior to 1980) were battery powered ionization detectors. Battery life has been a serious problem in the reliability of these older smoke detectors. Since 1980, new homes have been required to have AC powered smoke detector units installed. The new AC powered requirement allowed photoelectric detectors to be installed as well as ionization detectors since the AC power could provide sufficient power to sustain the photoelectric light source. There has been a migration toward photoelectric detectors since they rarely produce a nuisance alarm. However, the Air Force study shows there are significant concerns with the application of these detectors and the false sense of fire safety they provide when they are used in areas unsuitable to their design.

Tests show that households which periodically test their detectors have a much higher probability of having operative detectors. The national survey found that 70 percent of residences with occupant tested operative detectors had been tested within the last six months.[3]

Nationally, nuisance alarms account for approximately 32 percent of the failures of detectors. In these cases occupants experiencing nuisances alarms remove batteries and forget to replace batteries. These ionization units, alarm to invisible smoke associated with cooking oils (e.g. frying chicken and French fries). In Figure 1 are the results from the Smoke Detector Operability Survey on nuisance alarms.[4] Cooking smoke is the cause of 54% of the nuisance alarms. Frequently these types of alarms are caused because the detector has been mounted too close to the cooking area. Repositioning of the detector can eliminate many of these types of nuisance alarms. Bathroom water vapor is the second largest cause of nuisance alarms. Locating the detector far enough away from the bathroom will prevent this type of nuisance alarm.

The CPSC National Smoke Detector Project found that roughly half of inoperable smoke detectors were more than 10 years old. It is known that the "sensitivity" of smoke detectors varies with age. Detector sensitivity can either increase or decrease over time. If the sensitivity increases, the detector may produce "nuisance alarms". If the sensitivity decreases, the detector may fail to alarm in the presence of smoke.

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[2] Charles L. Smith, *Smoke Detector Operability Survey*, p. ii.

[3] Charles L. Smith, *Smoke Detector Operability Survey*, p. 11.

[4] Charles L. Smith, *Smoke Detector Operability Survey*, Appendix B, p. 11.

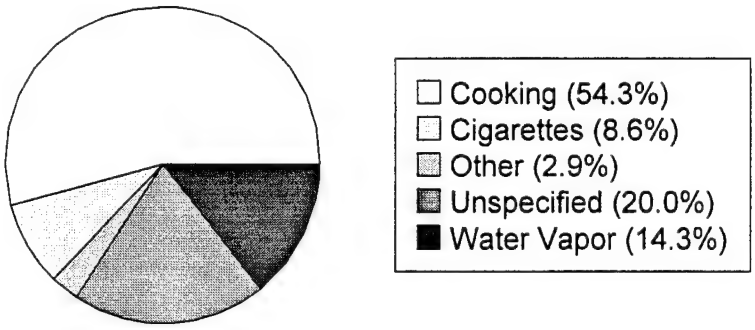

Figure 1. Nuisance Alarm Sources

A number of the tests accomplished by the CPSC indicated that the internal configuration of a smoke detector has a great deal to do with determining the service life of the device. Detectors with push connections and pressure contacts are much more likely to fail over time than devices with soldered connections. However the Air Force study showed that conditions, build up of dust and residue, were the more limiting factors on the service life of the detector. These factors appear to be more a function of detector type, detector location, and cooking methods. For example, ionization detectors located in close proximity to the kitchen area where occupants normally "fry" most foods will nuisance alarm within three years. Unfortunately Air Force housing maintenance personnel often replace the detector with a photoelectric unit since it will not nuisance alarm. This provides the occupant a false sense of security, since the unit's light sensing device will become coated and not alarm to fire.

As a result of the performance uncertainty associated with older smoke detectors, the National Fire Protection Association (NFPA) is now recommending that smoke detectors be replaced after 10 years.

C. SCOPE

An evaluation of the operability and reliability of smoke detectors currently installed in military family housing was conducted. The evaluation was conducted at four different bases and included a sufficient number of housing units to establish a high confidence level in the predicted operability and reliability rates. The four bases surveyed were Tyndall AFB, FL; Columbus AFB, MS; Maxwell/Gunter AFB, AL; and Keesler AFB, MS.

Detector testing was performed on site using a Model 501 Aerosol Generator/Smoke Detector Analyzer, manufactured by Gemini Scientific Corp. Testing was conducted in accordance with the Test Protocol recommended by Gemini Scientific Corp. This Test Protocol (extracted from the Model 501 User's Manual) is summarized in Section II.

Laboratory analysis was conducted on all units failing to meet the UL Standard during field testing. A sampling of fully operable units was made to determine the degradation of these units with respect to time. Primary interest was the build up of residue, corrosion of contact points, loss of sensitivity due to degradation of light sending and receiving sources and changes in current associated with the degradation of radiation sources or contamination in the ionization chamber.

SECTION II

TEST PROTOCOL

This Test Protocol is extracted from the User's Manual for the Gemini Model 501 Aerosol Generator.

A. GENERAL OBJECTIVE

The Gemini 501 Analyzer was designed to perform on site inspection of installed smoke detectors to determine their sensitivities. Sensitivity is defined as the amount (concentration in mg/m^3 or obscuration in %/ft) of smoke needed to trigger the alarm in the detector.

Normally only a single test is needed for routine sensitivity inspection of detectors. In that case, the test detector will alarm when it is exposed to the smoke concentration value equal to the nominal sensitivity specified by the manufacturer. However, if the detector did not alarm, additional tests are required. Since the test being conducted was accomplished in the military family housing unit and the detector did not alarm at the nominal sensitivity specified by the manufacturer, the amount of smoke was increased until the detector would operate. If a detector failed to operate it was replaced and brought back to the laboratory for further testing to determine the cause of failure.

B. LEGAL AND TECHNICAL AUTHORITIES

- *National Fire Protection Association* (NFPA) publishes the NFPA 72 National Fire Alarm Code (1993). It recommends evaluation of smoke detector sensitivity within one year after installation and every alternate year thereafter to see whether the detector is operative and produces the intended response. However this requirement does not apply to house-hold fire warning equipment i.e. smoke detectors installed in family housing units

- *Underwriters Laboratories,* through its UL-268 standard considers detectors to be acceptable if its sensitivity is between 0.5 and 4.0%/ft obscuration when exposed to the visible (gray) smoke in a UL smoke chamber.

- *Authority Having Jurisdiction.* The Fire Marshal or Fire Chief at the state or local level is responsible for enforcing their published standards or codes. These standards generally follow some national standards with or without modification to suit the local needs. For example, the Boston Fire Department requires detectors located in elevator waiting areas to meet a sensitive of 3.0%/ft or higher. This is to avoid frequent false alarms resulting from smoldering cigarettes passengers leave prior to boarding the elevators.

C. SENSITIVITY RANGES

Smoke detector manufactures are required by UL to specify the nominal sensitivity range of their production detectors. The ranges vary widely among manufactures and between types of detectors. Typically, nominal sensitivity for a photoelectric type detectors are about 3.0± 0.5%/ft and for an ionization type detector is about 1.5% ± 0.5%/ft.

All detectors of a given model may not necessarily fall within the extreme values provided by the manufacturer. Consult the manufacturer, if necessary.

Because of the built-in uncertainty of ± 0.4%/ft in relating field test results from the Gemini 501 to that of the UL smoke chambers, detectors with results ± 0.4%/ft beyond the given range may be considered acceptable. As an example, results as high as 2.4%/ft may be considered acceptable if the listed sensitivity is 1.5 ± 0.5%/ft.

D. TEST PROCEDURES

Start the test with the nominal sensitivity value given by the manufacturer. Depending on the test result, you can stop or do additional tests using either the upper or lower limit of the sensitivity range. For example, it the specified sensitivity is 1.5 ± 0.5%/ft, your first test would be 1.5%/ft and your second test could be 1.0%/ft (1.5 - 0.5), 2.0%/ft (1.5 + 0.5) or no test depending on the result from the first test. The third test , if needed, could be 0.6%/ft (1.5 - 0.5 - 0.4) or 2.4%/ft (1.5 + 0.5 + 0.4).

Start testing after the initial warm-up period and total emulsification of the liquid in the reservoir. The correct readings for the Magnehelic, pressure gage, and the flowmeter are 5.0 mm, 15 psig, and 0 respectively.

Place the shroud over the test detector. Adjust the flowmeter reading to the desired level shown by the appropriate scale. Reset or note the timer as you begin. If the detector **alarms** within 30 seconds, hold the shroud in place while you reduce the concentration to zero immediately and turn the pump off. Wait an additional 5-10 seconds before removing the shroud and shutting off the blower.

If the detector **does not alarm** within 30 seconds, increase the concentration to the next higher value with the shroud in place. Wait 30 more seconds for it to alarm.

If the test detector alarms and you want to continue the test at a lower setting, you must reset the alarm and allow at least 20 seconds to flush out the old smoke with the shroud in place.

If you recommend rejection of detectors based on sensitivity test results, make sure that your tester is in calibration and would survive challenges from the manufacturer or Authority Having Jurisdiction.

E. CALIBRATION AND ACCURACY

Each instrument is calibrated individually. The calibration curve relates instrument flowmeter readings to smoke output in terms of its mass concentrations (mg/m^3) and to its corresponding UL-268 light obscuration (%/ft) scales for the ionization and photoelectric detectors.

The curve is based on tests performed with pressure at 15 psig, dilution air at 5.0 mm (135L/min) and aerosol temperature at 75° F. Expected smoke output for temperature at 70° F and 80° F are also shown.

Estimated uncertainty based on a study relating detector sensitivity test results between the UL-268 Smoke Box and the Gemini 501 Tester is ± 0.4%/ft. This included operator as well as errors from the two measurement systems.

Detailed calibration techniques for the Gemini 501 tester are described in the user's manual.

F. DATA COLLECTION

All data was recorded on the data collection sheet contained in Appendix 1.

SECTION III

TEST RESULTS

Tests were conducted at Tyndall AFB on 2-3 Dec 94, at Maxwell/Gunter AFB on 3-6 Jan 95, at Columbus AFB on 12-16 Dec 94, and at Keesler AFB on 23-27 Jan 95. A total of 369 units were tested. A summary of the results are shown in Figure 2 and described below:

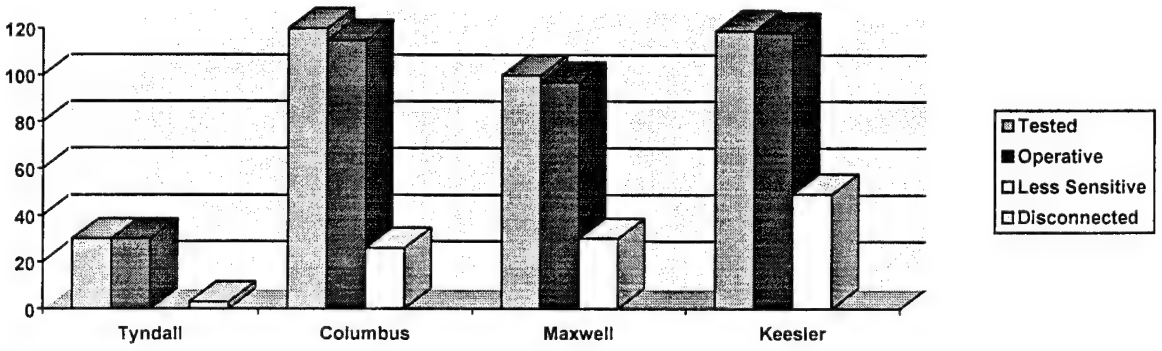

Figure 2. Air Base Test Results

A total of 30 ionization type detectors were tested at Tyndall AFB and all were found to be operational. Only 30 units were tested because all of their smoke detectors were replaced approximately 3 years ago. The 30 units tested all functioned according to the manufacturer's data and therefore it was felt that nothing could be gained from further testing. The type units installed are AC powered with battery backup. All units function within the manufacturer's sensitivity rating. Three units were found disconnected from the AC power because of "chirping". When the battery is dead or removed, the unit will operate in the AC mode; however, a constant chirping is sounded to remind the occupant that the battery needs replacing. When the batteries were replaced the units were found to be fully operational.

A total of 120 units were tested at Columbus AFB. Five detectors were found to be inoperative, all of these were photoelectric detectors. These detectors were among the first type installed in MFH during the 1970s. The five detectors were replaced and brought back to be tested in the laboratory. The units light sources were found to be excessively dirty. The sensitivity of 26 detectors were found to be outside the manufacturer's sensitivity specifications. Though not excessively dirty, dust build-up had caused them not to function at the manufacturer's rating (2.0%/ft). The units functioned when the amount of smoke was increased. Eleven units worked at 2.5%; 8 worked at 3.0%; and 7 worked at 3.5%, all were within the Underwriters Laboratory - 268 limit of 4.0%. All 26 units were photoelectric detectors from the same manufacturer only different models.

A total of 100 units were tested at Maxwell/Gunter AFB and three detector discrepancies were found (one detector was not connected to electrical source, another removed due to nuisance alarm and one unit failed to function due to dirty contacts). Thirty units were found to be outside the manufacturer's sensitivity specifications. However; these units operated within the UL-268 4% limit level for smoke concentration when tested. All 30 were photoelectric detectors from the same manufacturer only different models, in excess of ten years old. Dust accumulation was the primary cause of malfunction.

A total of 119 units were tested at Keesler AFB and one detector was found to be inoperative. Forty nine detectors were found to be outside the manufacturer's sensitivity specifications. However, those 49 detectors operated within the UL-268 4% limit level for smoke concentration when tested. All 49 units were photoelectric detectors from the same manufacturer only different models. These units were in excess of ten years old and had significant dust accumulation.

In summary, a total of 369 detectors manufactured by 12 different companies were tested. One hundred and eighty nine were photoelectric, and 180 were ionization detectors. Three hundred and sixty (96.7%) were operative. Except for Tyndall AFB, all of the detectors tested were installed in the 1970s. One hundred and five (55.6%) of the photoelectric detectors were found to be less sensitive than specified by the manufacturer. None were found to be more sensitive than specified.

Figure 3 shows that twice as much smoke is required for activation of photoelectric detectors as ionization detectors. Ionization detectors have a usable life of ten plus years except when located near cooking sources. Mislocation of ionization detectors can cause nuisance alarms reducing the usable life to five years or less. Photoelectric detectors though excellent for hallways and bedroom areas, will have a usable life of ten years plus. However, they must not be located adjacent to cooking areas or they can fail to alarm due to grease residue in as little as 2 years.

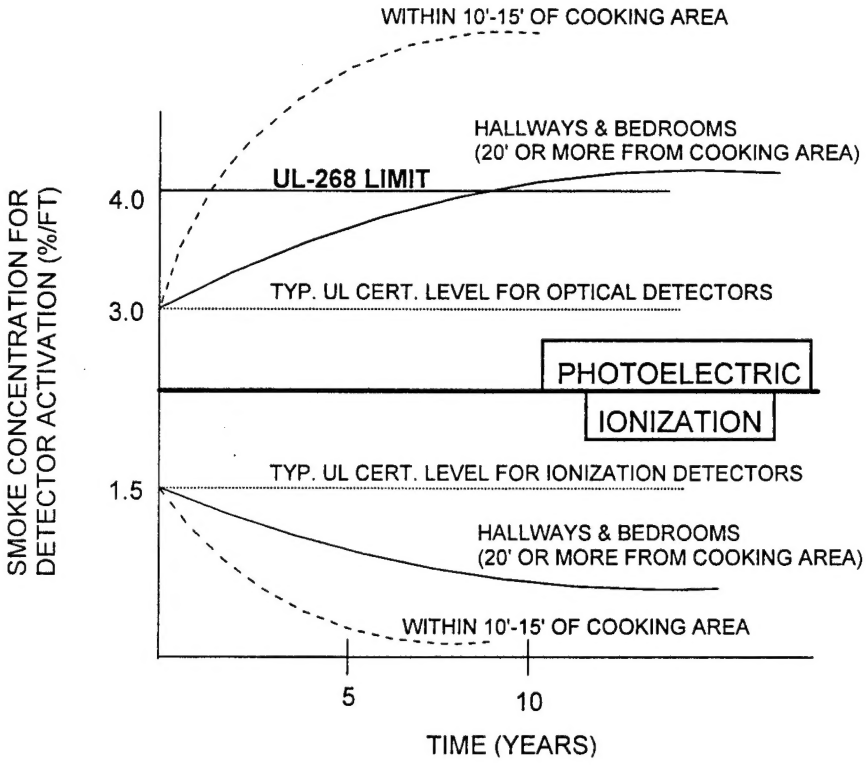

Figure 3. Variation in Smoke Detector Sensitivity with Time

SECTION IV

CONCLUSIONS

The results from the survey of four Air Forces bases shows that the Air Force does not have nearly the problems with smoke detectors that the Consumer Products Safety Commission indicated the country experiences. Ninety five percent of Air Force smoke detectors are in working condition versus 73% nationally. This wide disparity is due primarily to the fact that the civilian community still has a large number of battery powered smoke detectors in use. Ninety five percent of the problems associated with battery powered units can be attributed to dead or missing batteries. While a significant percentage of Air Force detectors tested were outside of the manufacturer's sensitivity specification, 95% of these detectors, though they were less sensitive than they should have been, still operated within the UL-268 4% smoke concentration limit.

The following conclusions are based upon analysis of the data obtained from Air Force field testing and laboratory analysis of detectors.

1. Smoke detectors on Air Force bases should be replaced after 10 years of service life. The national survey and Air Force test data clearly shows that dust and bugs inside the smoke detector is a significant problem in photoelectric detectors, causing failure or loss of sensitivity. Dust accumulation does not appear to be a problem in units less than 10 years old unless the unit is adjacent to a cooking area. It appears that Air Force housing maintenance personnel have systematically replaced ionization type units with photoelectric units in areas near cooking sources due to nuisance alarms from ionization detectors. This action has provided a false sense of fire safety because the photoelectric unit soon becomes coated with dust/grease and will not function. This inoperability can occur in as little as three years. Ionization detectors are the most reliable detection device; however, they must be located at a sufficient distance from the cooking source to insure the occupant does not disable the unit due to nuisance alarms. Although manufacturers recommend cleaning, duplicating manufacturers recommended cleaning procedures both in the field and in the laboratory shows this practice to be impractical.

2. Full detection test capability for **optical detectors** is not only desirable but **essential** to insure operability. Most detector occupant tests only provide a test of the alarm circuit. For photoelectric detectors this test capability is totally inadequate. Newer photoelectric devices have a built in reflective device to direct light from the light emitting source into the photo sensitive cell simulating the presence of smoke. This new feature, though it provides a significant margin of safety over the existing units requires the occupant to periodically activate the test function to insure the detector will respond to a fire situation. Ionization detectors have the **safety advantage** that when they fail due to dust or buildup of grease they emit a nuisance alarm.

3. The National Fire Protection Association recommends that occupants test detectors once a month. This is the minimum frequency necessary to ensure the safety of the occupants. In practice this is **unrealistic**. The recommended alternative for the Air Force to provide fire safety for housing occupants is to:

a. Provide ionization detectors for contamination prone areas (areas adjacent to cooking sources).

b. Provide photoelectric detectors only in bedrooms (these detectors should have full circuit test capability).

c. Replace photoelectric detectors after **10 years** of service life due to loss of sensitivity from dust.

d. Replace ionization detectors adjacent to cooking areas at a **maximum of five years**. Otherwise the unit will become extremely sensitive and nuisance alarm from grease buildup.

e. Use only AC powered non-battery back-up units.

Appendix 1

DATA COLLECTION SHEET

Date: _____ Time: _____ Test Conductor: _____

Location: _____AFB **MFH#: _____**

# of Detectors in MFH Unit: _____ (Complete test sheet for each detector unit)

Detector Type: Ionization, Photoelectric Power Source: Battery, AC, AC w/ battery

Date of Installation: _____ Detector Location: _____

Date of Manufacture: _____ Make/Model: _____

Identifying #s (UL etc.): _____ Sensitivity Rating: _____

Responds to Test Button: Yes, No Sensitivity Test Results: Pass/Fail

Condition of Detector: (Circle all that apply)

Missing Battery
Battery Disconnected
Dead Battery
AC Power Disconnected
Missing Cover
Insects/Cobwebs
Clogged with Dust/Dirt
Other (Specify): _____